Validation of 3-D Acoustic Modeling of Commercial Codes for Microfluidic Systems

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Nearly-ideal, single-node, planar standing waves can be modeled and established experimentally for waves that are centered in rectangular microfluidic flow channels. However, similar single-node, planar standing waves that are proximate to one wall of such a microchannel have never been realized experimentally. It is unclear whether the non-ideality arises from intrinsic defects and inhomogeneities in the materials that are used in such microsystems or whether it arises from non-ideality in the assembly/bonding/packaging.

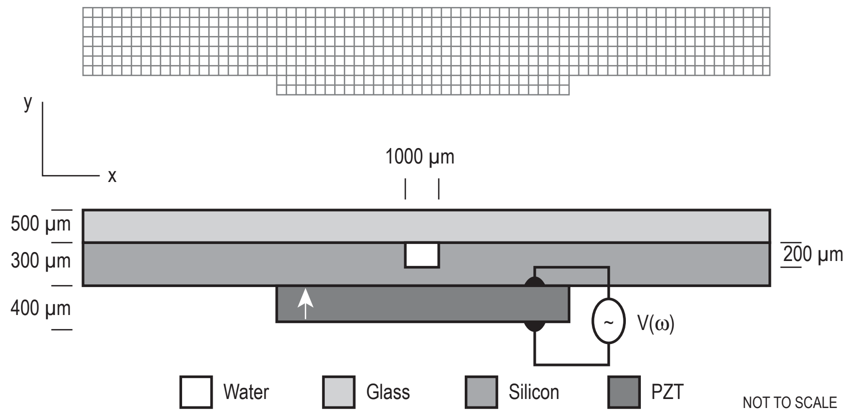
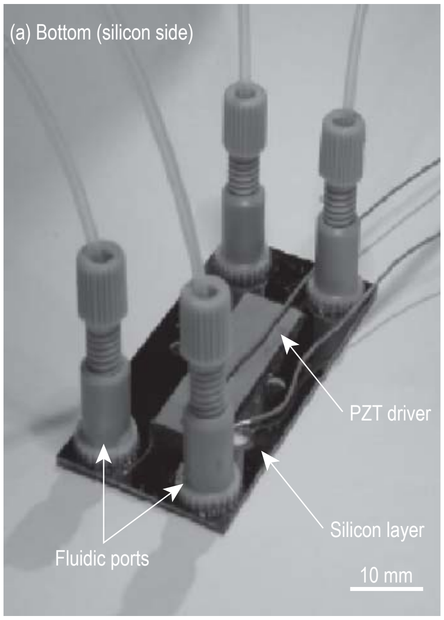
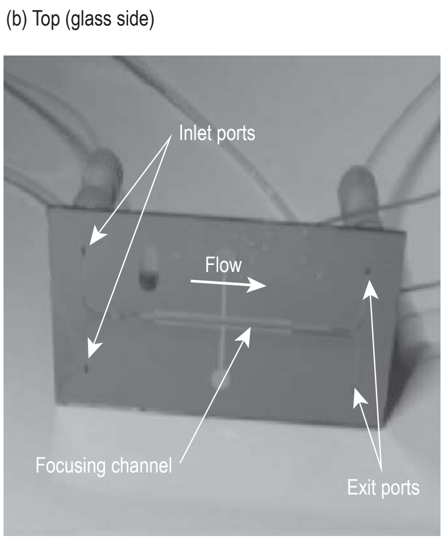


Figure 1. Two-dimensional computational region for the ATILA finite element code. The planar structure is comprised of an upper glass layer, and a silicon wafer in the middle with a fluidic channel etched into the upper surface. The structure is acoustically driven into resonance by a thin thickness-poled PZT layer, bonded to the bottom of the silicon wafer. The fluid flow is perpendicular into the modeled plane. Dynamic flow behavior of the fluid is not taken into account in this approximation.

Figure 2. The experimental microfluidic chip (H-bridge) test package, owing to similar designs found in the literature. Here, the PZT is bonded to the silicon layer, and plastic surface-mounted fluidic ports are used to couple the fluid and beads from a syringe pump into the focusing channel. The channel splits at the ends resulting in two inlet and two exit ports. A wide variety of separation, mixing, and fractionation schemes can be realized with this design.





Project Goals

Our goal is to use an existing code, ATILA, that can be used to perform 1-D, 2-D, and 3-D modeling of acoustic waves at ultrasonic frequencies within microsystems. We can use this capability to simulate the ultrasonic pressure fields in a variety of structures with microchannels that could be used to manipulate particles of scale 2 µm or larger in water or similar aqueous fluids, including possible generation of nearly-proximate standing waves. We also have fabrication expertise to test and validate the accuracy of these simulations. We compared these simulations with experimental measurements on microchannels in a variety of structures with microchannels passing particle-bearing fluids in order to validate these simulations on relevant microsystems.

Relevance to LLNL Mission

Acoustic manipulation of µm-scale particles is important for biosecurity applications and for biological sample handling and processing. Sample processing is still performed in a tedious, manual manner today, requiring large amounts of time from skilled technical personnel. Having a validated simulation capability to model acoustic manipulation of particles will significantly enhance LLNL's engineering capabilities.

FY2007 Accomplishments and Results

We used a commercial code, ATILA, which is already available, to perform 2-D and 3-D modeling of relevant possible structures with microchannels and bonded piezoelectric transducers. This enabled the fabrication and testing of several generations of microfluidic systems with ultrasonic transducers bonded to enable the manipulation of particles larger than 2-µm diameter via acoustic standing waves. We have experimentally validated 1) the code at the resonant frequencies of the ultrasound for our configurations, where larger particles are captured at the nodes of standing waves; and 2) the fact that sub-1-µm scale particles are largely unaffected by non-cavitating power levels of standing waves in the microfluidic channels.

The ATILA code and our results are shown in Figs. 1 to 4.

Related Reference

Coakley *et al.*, "Spore And Micro-Particle Capture on an Immunosensor Surface in an Ultrasound Standing Wave System," *Biosens. Bioelectron.*, **21,** pp. 758-767, 2005.

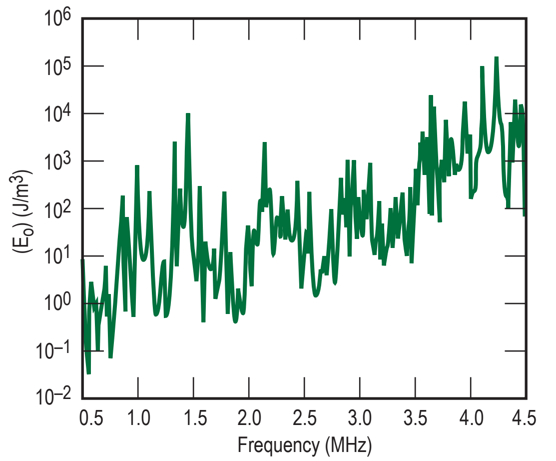
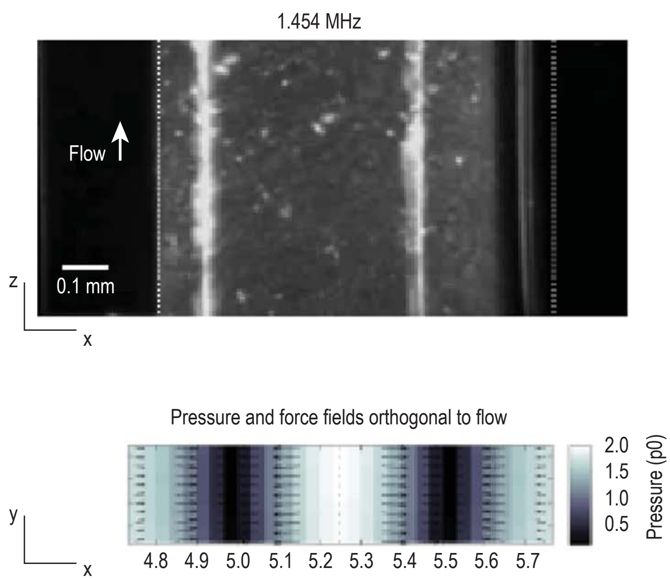


Figure 3. Theoretical energy density as a function of frequency for the 2-D channel described in Fig. 1. The amplitude of the drive voltage is 1 V. Several frequencies show energy densities in excess of 5x10^3 J/m^3. Large energy densities indicate potentially useful operating conditions for manipulation of particles. Conversely, there are regions where there is very little energy in the fluid, implying that all of the energy is in the elastic structure.



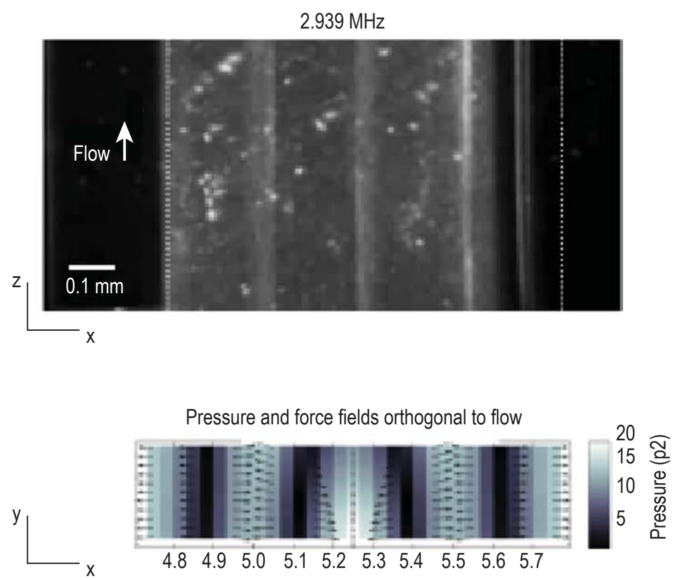


Figure 4. Two representative operating conditions of the microfluidic channel f = 1.454 MHz and 2.939 MHz. The upper images are microscope views of the channel through the glass substrate as the fluid and latex spheres flow from the inlet to the exit through the standing wave pattern in the channel. The lower images are the 2-D numerical estimate of the pressure field from ATILA and a vector plot corresponding to the direction of the calculated acoustic force fields. Here the dark regions represent nodes in the sound field and the light regions are antinodes.